Quantitative Dye Studies to Evaluate the Spill Response System for Mammoth Cave National Park

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Mammoth Cave National Park, an International Biosphere Reserve since 1990, is the world's largest cave with over 400 miles of surveyed passages and a cave ecosystem that is linked to the surface through groundwater recharge. Groundwater, the major component of the cave's formation by causing erosion and dissolution of limestone, still plays a vital role in the continued geomorphic processes that form the cave and its ecosystem. However, the same hydrologic processes that form the cave, make the karst system vulnerable to contamination. With over 500,000 visits per year, it is expected that occasional accidents and spills will occur on the surface. Recharge areas without storm filters and containment basins risk exposing the cave ecosystem to spilled contaminants. The objective of this study was to determine if two temporary small check dams impede chemical transport from the surface into the cave.

The check dams were approximately 2 feet high, 2:1 slopes, and located 100- and 500-feet below tracer release point. Three quantitative tracer studies tests were conducted to test the effectiveness of the check dams. The presence and absence of the check dams were the main variables in the studies. The tracer release point chosen was from a potential contamination source on the surface and the dye was monitored at upper and lower cave passages.

The surface flow channel used in this study was approximately 1,500 feet in length from the tracer release point to the sinkhole. Rhodamine WT-20 dye was released in August, October, (2014) and January (2015) in conjunction with either the onset of storm runoff or as the storm was winding down. Prior to each dye release, the absence of dye was verified by monitoring waters in the cave streams a minimum of three consecutive storms before releasing the dye. The monitoring equipment was placed in the upper and lower cave passages, Cataracts and Cascade Hall area in Silliman Ave, respectively.

Continuous monitoring from June, 2014, through January, 2015, was accomplished using two portable field fluorometers. Additional monitoring for the second tracer study was achieved using 12 passive charcoal sampling devices. For the first test on August 31, 2014, the rainfall depth was a 2.4 inch rain event and 180 milliliters (mL) of Rhodamine were released on the rising limb of the storm runoff. The two check dams were still in place along the surface flow routes. There was a tracer breakthrough in the upper cave passage 9.7 hours after the dye was released. Sixteen hours after the time of the release, approximately half of the recovered dye (center of mass) had moved past the monitoring station in the upper cave passage (Cataracts). The total amount of dye accounted for was approximately 4 mL out of the 180 mL released, which is less than 3% of the tracer used in this study.

We were unsuccessful at detecting any dye in the lower level because of bad placement of the second fluorometer. The second test was initiated on the evening of October 13, 2014 during a 2.1 inch rain event. Both check dams had been removed for this study to estimate the amount of time it would take for the dye to reach the cave with no obstacles. Also, 12 passive charcoal samplers were placed in a variety of locations in the lower level of the cave. Rhodamine dye (600 mL) was released in the rising limb of the storm runoff. During this study it took 4 hours for the dye to be detected in the upper cave passage (Cataracts).

The total amount of dye accounted for via concentration and discharge was 262 mL out of the 600 mL released (43%). Although the fluorometer in the lower cave passage failed to detect any dye again, there were positive tracer results at 5 of the 12 passive sampling locations. Therefore, the fluorometer in the lower cave passage was moved to one of the locations with a positive hit before starting the third tracer study. In the final tracer test on January 3, 2015, 600 milliliters of Rhodamine were released on the declining limb of the storm (a 0.7 inch storm) and was detected in the upper cave passages within 50 minutes. Approximately 38% of the dye was accounted for in the upper cave passage. Trace amounts were detected in the lower level approximately 3.5 days later. Furthermore, subsequent storms produced additional tracer data in the upper cave passage that accounted for another 7% of the dye used in the study. The maximum tracer amount recovered was 288 mL of dye which was 45% of the total amount of dye released. Additional dye detections in subsequent storms had not occurred in the previous two tracer studies. The tracer peaks associated with successive storms after the third study were probably because of the timing of the tracer release in the receding portion of the storm runoff, resulting in tracer transport stalling along the flowpath. Overall, these studies demonstrated that placing the two small check dams along the surface flowpath resulted in lengthening the time-of-travel from 2 hours to 16 hours. It also reduced the amount of dye entering the cave by 90%. Lastly, the third study showed that a chemical released in the last quarter of a storm, may be transferred faster into the cave than chemicals released in the rising limb, with a portion prone to temporary storage.

Additional work is needed to account for the remaining tracer and to better understand the transport and storage mechanisms.

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